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**Christensen et al.**

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(54) **COMPOSITE DOME CONNECTORS FOR FLYWHEEL RIM TO SHAFT ATTACHMENT**

(71) Applicant: **Orbital ATK, Inc.**, Dulles, VA (US)

(72) Inventors: **Brian R. Christensen**, Willard, UT (US); **Marcus A. Darais**, Brigham City, UT (US)

(73) Assignee: **ORBITAL ATK, INC.**, Plymouth, MN (US)

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**F16F 15/305** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **F16F 15/305** (2013.01); **Y10T 74/2132** (2015.01)

(58) **Field of Classification Search**  
USPC ..... 74/572.1, 572.11, 572.12, 572.21  
See application file for complete search history.

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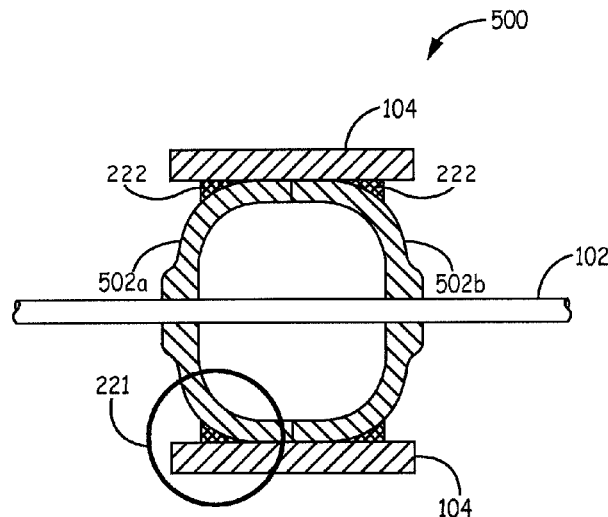
Primary Examiner — Vicky Johnson

(74) Attorney, Agent, or Firm — TraskBritt

(57) **ABSTRACT**

A dome connector for a flywheel rim to shaft attachment is provided. The dome connector includes a helically wound composite band that extends from a first port to a second port. The helically wound composite band has a helical angle in relation to a line perpendicular to a center of axis of the dome connector. The helical angle is selected to at least in part achieve a desired stiffness in the dome connector.

**20 Claims, 10 Drawing Sheets**



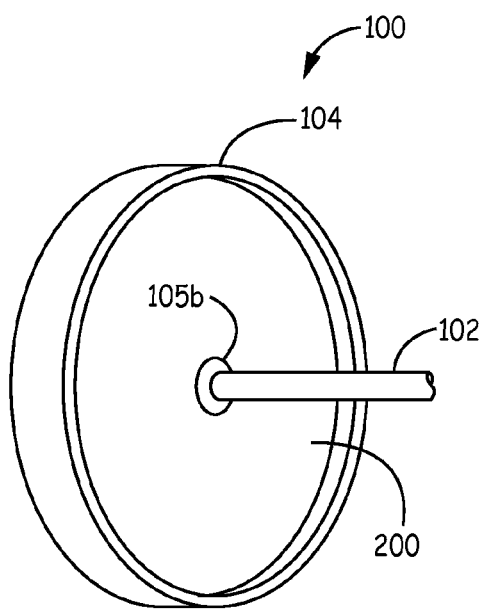


FIG. 1A

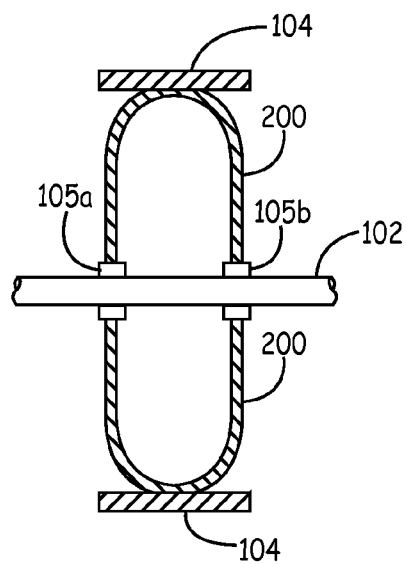


FIG. 1B

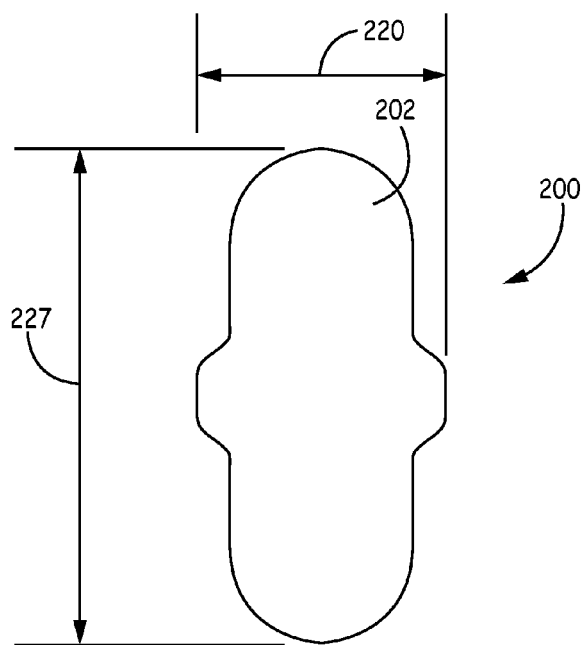


FIG. 2A

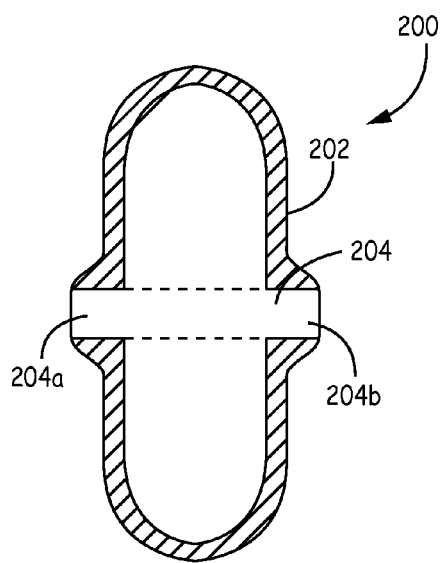


FIG. 2B

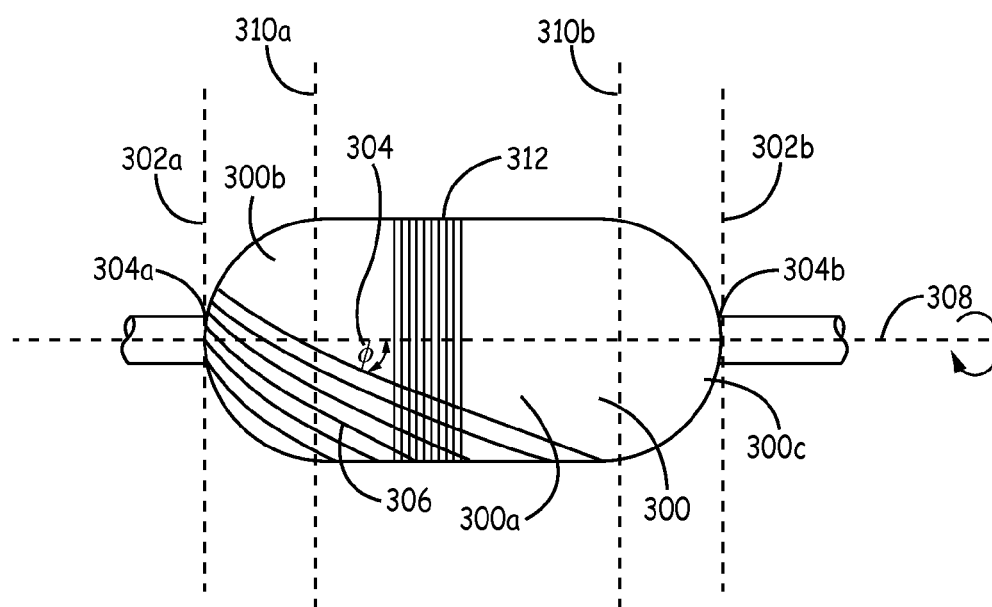


FIG. 3

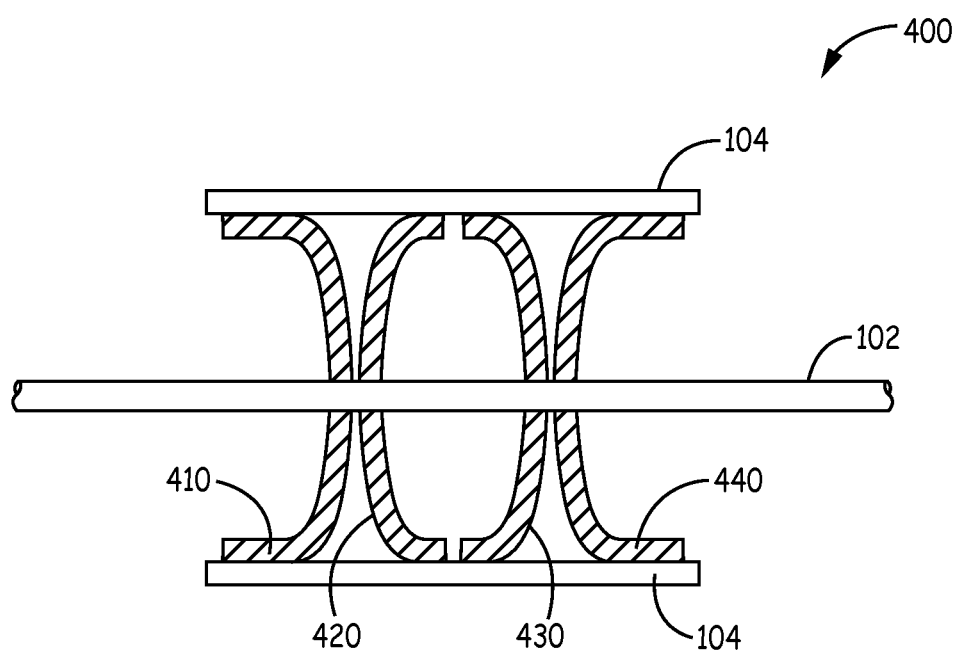


FIG. 4

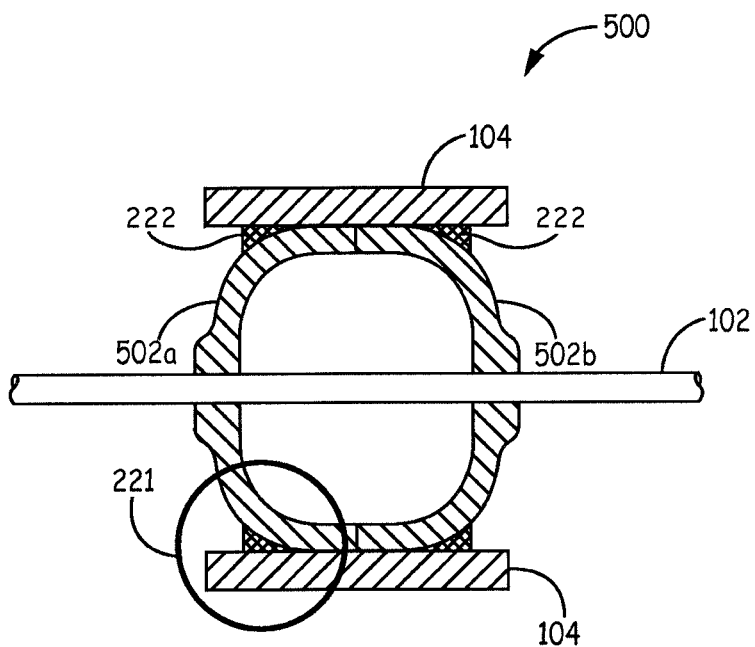


FIG. 5A

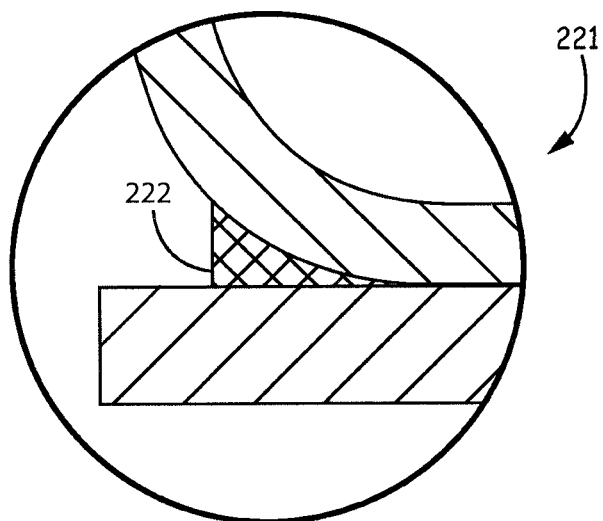


FIG. 5B

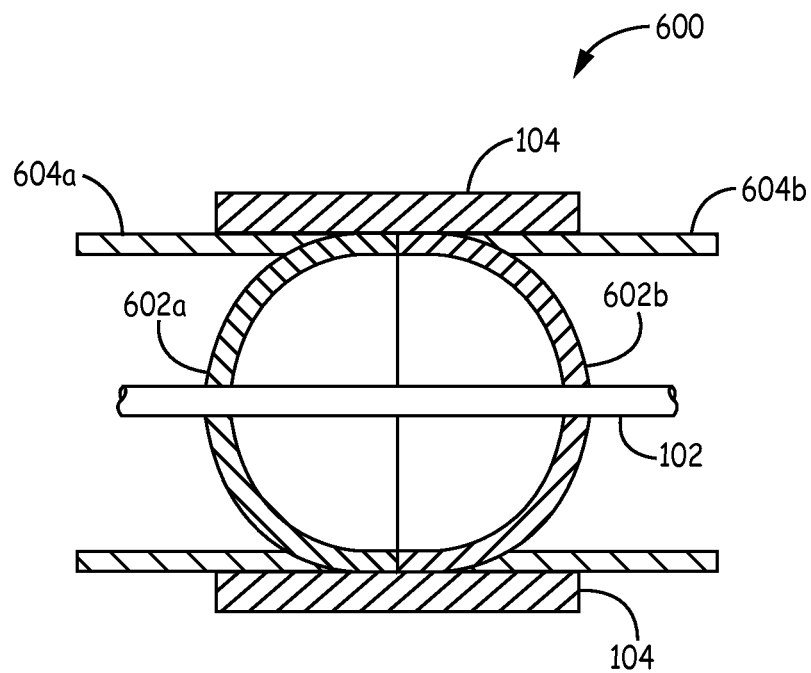


FIG. 6A

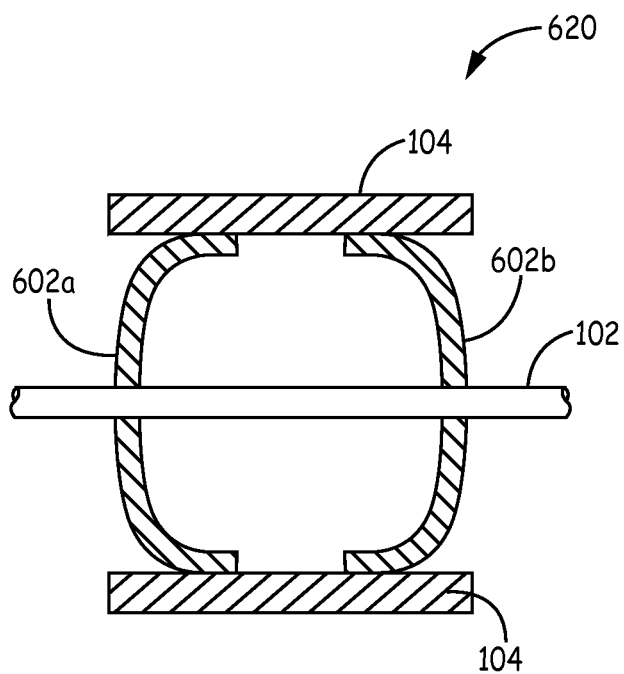


FIG. 6B



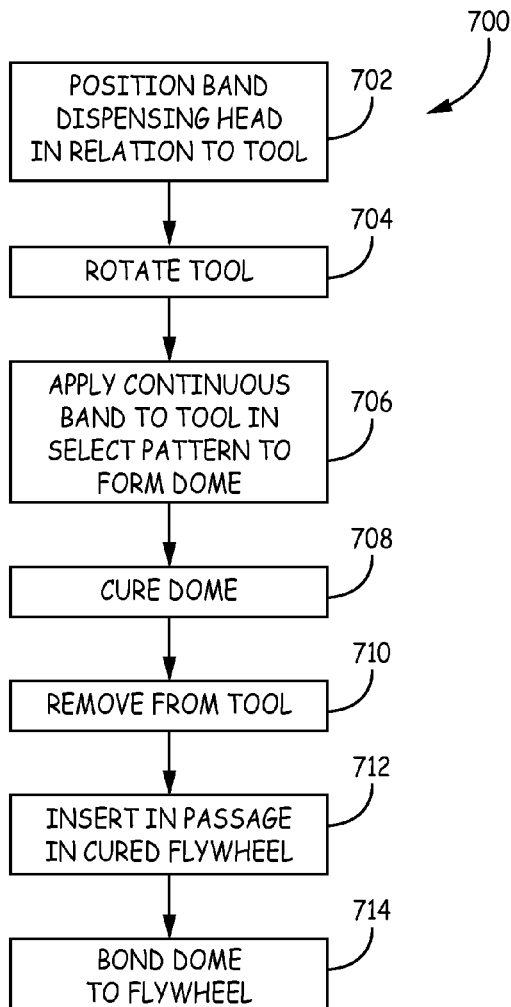


FIG. 7

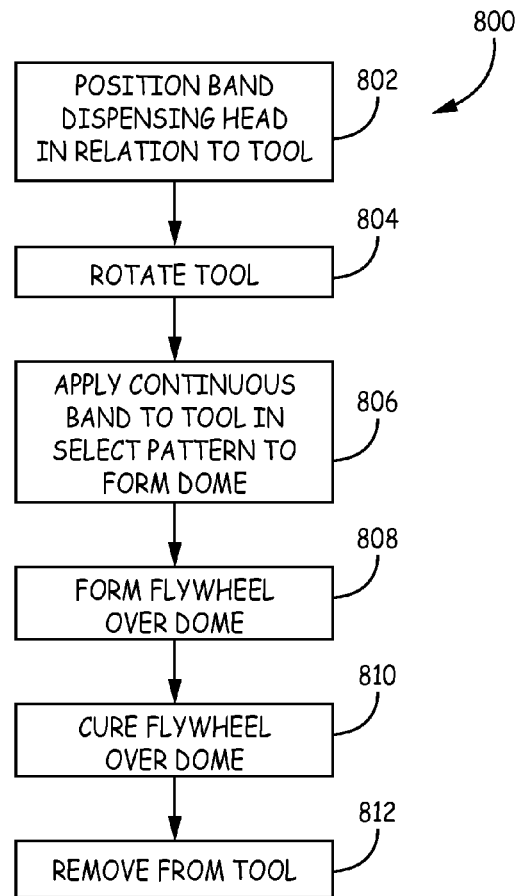
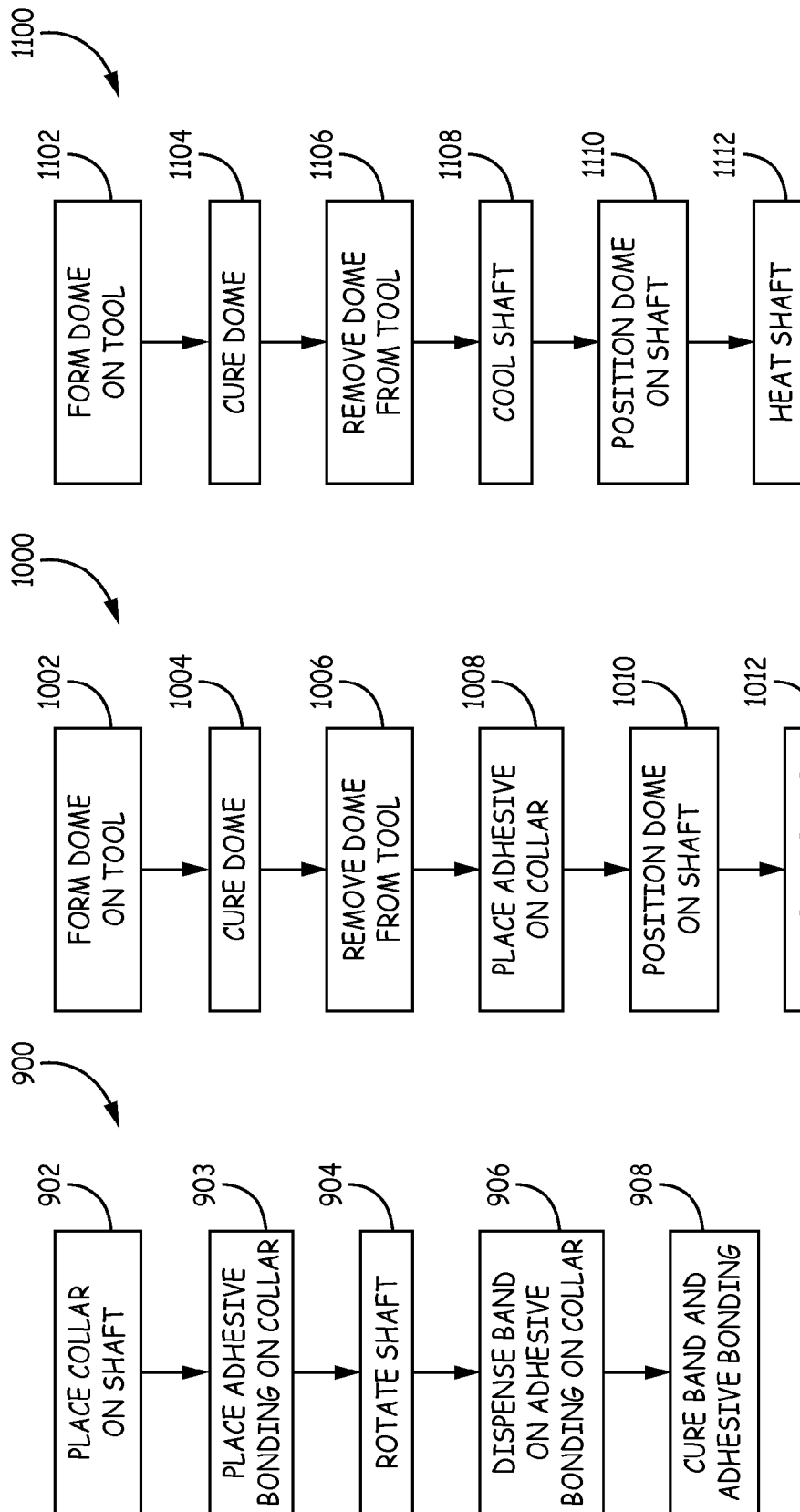


FIG. 8



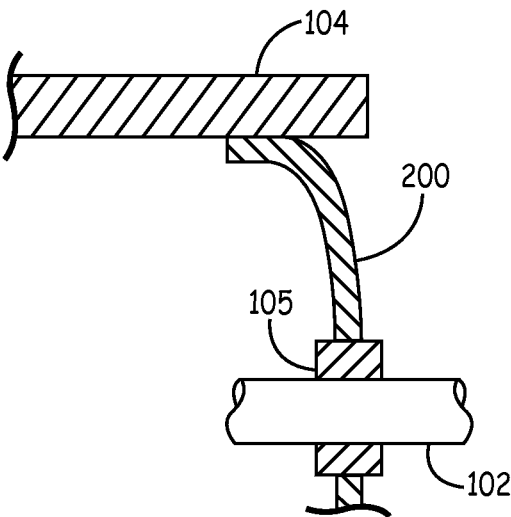


FIG. 12

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**COMPOSITE DOME CONNECTORS FOR FLYWHEEL RIM TO SHAFT ATTACHMENT****BACKGROUND**

Composite flywheels such as carbon composite flywheels are desired because they are strong while having a light weight (this is known as having a high specific strength). It is common for the composite flywheels to be connected to a metal shaft for the purpose of putting in or taking out kinetic energy from the flywheel. A common limiting factor for high-performance carbon composite flywheels, or other high-strength fiber composite flywheels, is the connection of the radially expanding (high strained) flywheel rim to the metal shaft, which expands much less (due to its smaller diameter). Typical composite/metal connections do not have sufficient stress/strain capabilities and connections, such as geometrically compliant metal spokes, which lead to dynamic instability. Moreover, connecting flat composite plates, with fibers oriented in a radial direction or near radial direction, form a shaft to rim connection, which produces unmanageable bond/fastener stresses. In addition, using very thick filament wound disks (with a majority of the fibers in the circumferential direction) results in unacceptable radial tensile stresses (across ply stresses) occurring in the hub.

For the reasons stated above and for other reasons stated below, which will become apparent to those skilled in the art upon reading and understanding the present disclosure, there is a need in the art for an effective, efficient and dynamically stable flywheel-to-shaft connection.

**SUMMARY**

The above-mentioned problems of current systems are addressed by embodiments of the present invention and will be understood by reading and studying the following specification. The following summary is made by way of example and not by way of limitation. It is merely provided to aid the reader in understanding some of the aspects of the invention.

In one embodiment, a dome connector for a flywheel rim to shaft attachment is provided. The dome connector includes a helically wound composite band that extends from a first port to a second port. The helically wound composite band has a helical angle in relation to a line perpendicular to a center of axis of the dome connector. The helical angle is selected to, at least in part, achieve a desired stiffness in the dome connector.

In another embodiment, a flywheel is provided. The flywheel includes a metal shaft, a composite flywheel rim and a dome connector. The dome connector couples the composite flywheel to the metal shaft. The dome connector includes a helically wound composite band that extends from a first port to a second port. The helically wound composite band has a helical angle in relation to a line perpendicular to a center of axis of the dome connector. A deflection characteristic of the dome connector generally matches a deflection characteristic of the flywheel rim.

In still another embodiment, a method of forming a coupling between a composite flywheel rim and a metal shaft is provided. The method includes: laying up a continuous band of composite fibers in a helical pattern from a first port to a second port to form a central passage with a first band layer; laying up subsequent layers with the continuous band of composite fibers over at least a portion of the

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first band layer to form a body; and curing the composite fibers to form a dome connector.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The present invention can be more easily understood and further advantages and uses thereof will be more readily apparent, when considered in view of the detailed description and the following figures in which:

FIG. 1A is a front perspective view of a flywheel assembly of one embodiment of the present invention;

FIG. 1B is a cross-sectional side view of the flywheel assembly of FIG. 1A;

FIG. 2A is a side view of a dome connector of one embodiment of the present invention;

FIG. 2B is a cross-sectional side view of the dome connector of FIG. 2A;

FIG. 3 is a side view illustrating the forming of a dome connector of one embodiment of the present invention;

FIG. 4 is a side view of a flywheel assembly with a dome connector configuration of one embodiment of the present invention;

FIG. 5A is a cross-sectional side view of a flywheel assembly of one embodiment of the present invention;

FIG. 5B is a close up view of a portion of the flywheel assembly of FIG. 5A;

FIG. 6A is a cross-sectional side view of another flywheel assembly being formed of one embodiment of the present invention;

FIG. 6B is a cross-sectional side view of another flywheel assembly of an embodiment of the present invention;

FIG. 7 illustrates a flywheel forming diagram of one embodiment;

FIG. 8 illustrates a flywheel forming diagram of another embodiment;

FIG. 9 illustrates a shaft connecting diagram of one embodiment;

FIG. 10 illustrates a shaft connecting diagram of another embodiment;

FIG. 11 illustrates a shaft connecting diagram of yet another embodiment; and

FIG. 12 is a partial side view of a flywheel assembly of one embodiment of the present invention.

In accordance with common practice, the various described features are not drawn to scale but are drawn to emphasize specific features relevant to the present invention. Reference characters denote like elements throughout the figures and the specification.

**DETAILED DESCRIPTION**

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that changes may be made without departing from the spirit and scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the claims and equivalents thereof.

Embodiments of the present invention provide a filament wound composite dome connector used for a flywheel rim to metal shaft connection. In embodiments, at least some of the filaments that make up the composite material that form the

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dome connector have winding patterns that are generically referred to herein as “helically wound.” Helically wound patterns include polar, planar or other opening-to-opening wind patterns used to form the domes. Hence, the term “helically wound” is a generic term that is used throughout the specification and claims that includes polar, planar and other opening-to-opening wind patterns used to form the domes. The helically wound dome connectors are able to strain with the rim, yet maintain dynamic stiffness. The dome connectors also minimize the stress concentrations placed on an inside diameter of the flywheel rim, which can be significant in other types of rim-shaft connections, such as hubs, as known in the art. This reduction/elimination of stress concentrations is important since the energy storage capacity of a flywheel is directly related to the maximum stress in the flywheel rim. Moreover, the compliance of the dome connectors allow for a match between a deflection in the dome connector (dome connector deflection) and deflection in the flywheel rim (flywheel deflection) that is encountered during rotation of the flywheel. In embodiments, dome connector geometry, fiber material type, material fiber thickness and wind angle of the fiber are tailored to achieve the desired deflection or stiffness required for a specific design. As discussed below in detail, dome connectors may be wound in place with the flywheel rim or post installed by: bonding, a press fitting, shrink fitting and the like. Post installation of the dome connectors allows for the use of a single dome connector or two or more dome connectors per flywheel rim. Additionally, in a multi-dome connector configuration, the orientation of the domes relative to each other can be in a convex-convex, concave-concave or concave-convex configuration as also discussed below.

Referring to FIG. 1A, a front perspective view of a flywheel assembly 100 of an embodiment that includes a flywheel rim 104, a dome connector 200 and a metal shaft 102 is provided. As illustrated, the flywheel rim 104 is coupled to the shaft 102 via dome connector 200. A cross-sectional side view of the flywheel assembly 100 is further illustrated in FIG. 1B. The dome connector 200 is coupled to the shaft 102 via attachment collars 105a and 105b in this embodiment. The attachment collars 105a and 105b are further discussed below in regard to FIG. 12. An illustration of an embodiment of a dome connector 200 is provided for in a side view of FIG. 2A and the cross-sectional side view of FIG. 2B. This embodiment of the dome connector 200 includes an outer surface 202 that is formed in a desired shape. A central passage 204 passes through the dome connector 200. At the opposed entrances to passage 204 in the dome connector 200 are respective first and second openings 204a and 204b (first port and second port). In some embodiments, the dome connector 200 has a dome length 220 extending along a distance of the central passage 204 and a dome diameter 227 extending a distance perpendicular to the central passage 204. In the embodiments of FIGS. 2A and 2B, the distance of the dome length 220 is less than the distance of the dome diameter 227. In other embodiments, the dome length 220 would be greater than or equal to the distance of the dome diameter 227.

The formation of a dome connector 200, such as dome connector 200 of FIG. 1A, is discussed in regard to FIG. 3. FIG. 3 illustrates a tool 300 in which a dome connector is formed in one embodiment. The dome connector 200 is made from a band of toes 306. Each toe consists of thousands of fibers such as, but not limited to, carbon and heat activated material such as pre-preg material as known in the art. The band 306 is wound around the tool 300 to form the desired dome shape. In particular, in one embodiment the

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band 306 is positioned by a band dispensing system (not shown), as known in the art, that includes a band dispensing head that selectively positions the band 306 via controller (not shown). The tool 300 is coupled to a portion of the dispensing system that rotates the tool 300 about the tool's center of axis 308 while the band dispensing head is moved axially, in relation to the tool 300, by the controller. Lines 310a and 310b are known as the “tangent” lines of the tool 300 that define a cylindrical portion 300a of the tool 300 from domes 300b and 300c of the tool 300. Between the tangent lines 310a and 310b is called “inboard” and outside the tangent line 310a and 310b is called “outboard.” In the embodiment of FIG. 3, overlaying hoop bands 312 are positioned over the cylindrical portion 300a of the tool 300. In one embodiment, the hoop bands 312 are not only applied to the cylindrical portion 300a, but also outboard of at least one of the tangent lines 310a and 310b down to the respective at least one dome 300b and/or 300c of the tool 300.

The embodiment of FIG. 3 depicts the band 306 at a first opening (port) position 302a and then the band 306 is wound around the tool 300 with the dispensing system (not shown) to a second opening (port) position 302b at a select helical angle 304 to form a select helical pattern from one port 304a to the other port 304b in the finished dome connector. FIG. 3 illustrates adjacent band loops having gaps for illustration purposes. In practice, as the band 306 is being laid out on the tool 300 in the helical pattern, there will be no gaps and no overlays (within a layer being formed) that would weaken the dome connector 200. When the band 306 reaches the second port 304b the dispensing head will reverse direction and lay down another helical pattern layer over the first helical pattern layer to the first port 304a. Further helical patterned layers are layered up on the tool 300 to form the dome connector 200. Hence, the dome connector 200 will consist of multi-helical patterned band layers. Specific dome geometries are achieved by winding on tools with different contours. As discussed above, the helical angle 304 is one variable that can be selected to achieve a desired characteristic of the dome connector 200 such as providing a matching deflection (or stiffness) with an associated flywheel rim 104 (FIG. 1A).

As discussed above, embodiments of the dome connector are effective because they are made with material that has low density but high strength and can be tailored to the stiffness of the flywheel rim 104 (FIG. 1A) by changing any one of the helical angles in the helical pattern, the geometry of the dome and the type of fiber used. Additionally, in domes that use more than one helically wound layer, one or more of the layers may be wound with a pull-back, which is winding the helical to some radius larger than the radius of the ports/collars. Using pull backs can effectively tailor the stiffness and strength of the dome and port regions. Regarding the geometry, by changing the contour of the dome to either relatively shallow or relatively deep, a desired stiffness or deflection can be achieved to match an associated flywheel rim 104. As discussed above, the dome connector can have either convex or concave ends and two or more dome connectors can be used per flywheel rim 104. For example, please refer to FIG. 4 where a flywheel assembly 400 having four dome connectors 410, 420, 430 and 440 is illustrated. The four dome connectors 410, 420, 430 and 440 of the flywheel assembly 400 are positioned next to each other with their respective inner passages aligned. The shaft 102 is mounted within the aligned inner passages of the four dome connectors 410, 420, 430 and 440. The flywheel rim 104 is fitted around the four dome connectors 410, 420, 430 and 440. As discussed above, dome connectors can have

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ends in different configurations (i.e., convex ends or concave ends) and embodiments are not limited to specific configurations or the number of dome connectors used in a flywheel assembly.

FIG. 5A illustrates a cross-sectional side view of a flywheel assembly 500 that includes dome connectors 502a and 502b of an embodiment. In this embodiment, y-joint connectors 222 are further used to couple the flywheel rim 104 to the dome connectors 502a and 502b. The y-joint connectors 222 are positioned between the flywheel rim 104 and the respective dome connectors 502a and 502b where the respective dome begins to curve away from the flywheel rim 104. A close up view 221 of a y-joint connector 222 is illustrated in FIG. 5B. The y-joint connectors 222 can be fabricated from rubber, elastomer, adhesive or other suitable material. The y-joint connectors 222 can be either co-fabricated with the flywheel-dome assembly 500 or after the dome connectors 502a and 502b are installed in the flywheel rim 104.

The forming of flywheel assemblies is further discussed below. In one embodiment, a dome connector (such as dome connector 200 of FIG. 2A) is first formed. A center cylindrical portion is then removed from the dome connector. Referring to FIG. 6A, the formation of a flywheel assembly 600 is illustrated. In this cross-sectional side view illustration, a dome connector is first formed and its center cylindrical portion is removed. The dome portions 602a and 602b of the dome connector are then positioned as illustrated with a shaft 102 extending through central aligned openings of the dome portions 602a and 602b. Temporary winding mandrels 604a and 604b are positioned in relation to the dome portions 602a and 602b. The winding mandrels 604a and 604b and portion of the dome portions 602a and 602b create a forming surface in which the flywheel rim 104 is wound around and formed. Once the flywheel rim 104 is formed, the winding mandrels 604a and 604b are removed. This embodiment allows for flywheels with smaller diameters. FIG. 6B illustrates another way of forming a flywheel assembly. In flywheel assembly 620, the dome portions 602a and 602b are first cured and then placed and bonded inside of a pre-cured flywheel rim 104.

A flywheel assembly forming diagram 700 of an embodiment is illustrated in FIG. 7. In this embodiment, the process starts by positioning a band dispensing head in relation to a tool (702). The tool is then rotated (704) and a continuous band is applied to the tool in a select pattern (706). As discussed above, the toe (or band) is laid down from one opening (or port) to the other port in a helical pattern having a select helical angle for at least a portion of the dome connector. Once the entire dome connector has been laid up, it is cured (708). The dome connector is then removed from the tool (710) and in this embodiment is inserted in a central passage in a cured flywheel rim (712) (similar to the discussion in regard to the embodiment of FIG. 6B). The dome connector is bonded with an adhesive within the central passage of the cured flywheel (714). Another embodiment of forming a flywheel assembly is illustrated in the flywheel assembly forming diagram 800 of FIG. 8. In this embodiment, the band or band dispensing head is positioned in relation to the tool (802). Once the dispensing head is in position, the tool is rotated (804). A continuous length of band is then applied on the tool in a select pattern to form the dome connector shape (806). In this embodiment, the flywheel rim is then formed over the dome connector (808) (similar to the discussion in regard to the embodiment of FIG. 6B where the flywheel may be built to extend past the tangent lines of the dome connector). This

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can be done with the use of the dispensing head or other methods known in the art for forming composite material. The dome connector and the flywheel rim are then cured together therein coupling the dome connector to the flywheel rim (810). In an embodiment, the cured flywheel rim and dome connector are then removed from the tool (812). The dome connector would then be connected to the shaft.

Connecting the dome connector to the shaft can be done in a number of ways. For example, in the embodiment of the shaft connecting diagram 900 of FIG. 9, the dome is formed on a shaft 102. In particular, in this embodiment, an attachment collar (such as attachment collar 105 of FIG. 12) is first placed on a shaft 102 (902). An adhesive is then placed on the collar 105 (903). The shaft 102 is then rotated (904). The continuous band is then dispensed on the adhesive on the collar in the helical pattern to form the dome connector (906). The dome connector is then cured and the adhesive bonds the dome connector to the collar 105 (908). In another embodiment, illustrated in the shaft connecting diagram 1000 of FIG. 10, the dome connector is formed on the tool as discussed above (1002). The dome connector is then cured (1004). The dome connector is then removed from the tool (1006). An adhesive is placed on the collar (1008). The dome connector is positioned on the shaft (1010). The adhesive is then cured to bond the dome connector to the collar (1012). This collar would then interface with a shaft used for flywheel operation. In embodiments, the adhesive may cure by heat, by drying out and the like. In another example, as illustrated in the shaft connecting diagram (1100) of FIG. 11, the dome connector is formed on the tool as generally described above (1102). The dome connector is then cured (1104). Once cured, the dome connector is removed from the tool (1106). The shaft that the dome connector is to be mounted to is then cooled which will cause it to contract (1108). While the shaft is cooling, the dome connector receives the shaft in its central passage (1110). The shaft is then allowed to heat, which causes the shaft to expand and bond in the central passage of the dome connector (1112). The above provides some example methods of coupling the dome connector to the shaft and the flywheel rim to the dome connector.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, which is calculated to achieve the same purpose, may be substituted for the specific embodiments shown. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

The invention claimed is:

1. A flywheel assembly comprising:

a metal shaft;

a composite flywheel rim;

a dome connector coupling the composite flywheel rim to the metal shaft, the dome connector including a helically wound composite band extending from a first port to a second port, the helically wound composite band oriented at a helical angle that is offset from a central axis of the dome connector and a line perpendicular to the center axis of the dome connector, wherein, at a first location, an inner surface of the composite flywheel rim and an outer portion of the dome connector are positioned adjacent each other and coupled together, and wherein, at a second location, the inner surface of the composite flywheel rim and the outer portion of the dome connector are spaced apart to define an annular opening between the inner surface of the composite

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flywheel rim and the outer portion of the dome connector at an axial end of the dome connector; and at least one connector positioned in the opening defined between the inner surface of the composite flywheel rim and the outer portion of the dome connector at the axial end of the dome connector, the at least one connector having a wedge shape comprising a first axial end positioned adjacent to the first location and a second axial end positioned relatively further away from the first location where the inner surface of the composite flywheel rim and the outer portion of the dome connector are spaced apart to define the annular opening, the second axial end exhibiting a width that is greater than a width of the first axial end.

2. The flywheel assembly of claim 1, wherein the helical angle is selected to at least in part achieve the generally matching deflection characteristic between the dome connector and the flywheel rim.

3. The flywheel assembly of claim 1, wherein the helically wound composite band comprises a body having a first end, a second end and a cylindrical middle portion positioned between the first end and the second end, the body further having a central passage, the central passage extending between the first and second ports.

4. The flywheel assembly of claim 3, wherein the first end and the second end of the body exhibit a generally convex shape, and wherein the first end and the second end of the body is placed within the flywheel rim such that an outer portion of the dome connector exhibits the generally convex shape.

5. The flywheel assembly of claim 4, wherein a portion of the flywheel rim engages the generally convex shape of the at least one of the first end and the second end of the body.

6. The flywheel assembly of claim 3, wherein at least one of the first end and the second end of the body is placed within the flywheel rim such that an outer portion of the dome connector exhibits a generally concave shape.

7. The flywheel assembly of claim 3, wherein the dome connector further comprises hoop bands extending around the dome connector in a direction substantially perpendicular to the central axis of the dome connector.

8. The flywheel assembly of claim 3, wherein a stiffness of the body substantially matches a stiffness of the flywheel rim.

9. A method of forming a coupling between a composite flywheel rim and a metal shaft, the method comprising:

forming the dome connector of claim 6 comprising:

laying up a continuous band of composite fibers in a helical pattern from a first port to a second port to form a central passage with a first band layer;

laying up subsequent layers with the continuous band of composite fibers over at least a portion of the first band layer to form a body of the dome connector; and

curing the composite fibers to form the dome connector; and

coupling the composite flywheel rim to the metal shaft with the dome connector.

10. The flywheel assembly of claim 1, wherein the at least one connector comprises at least one of a rubber, an elastomer, and an adhesive.

11. The flywheel assembly of claim 1, wherein the helically wound composite band comprises a body having a first end, a second end and a cylindrical middle portion positioned between the first end and the second end, the body further having a central passage, the central passage opening to the first port and the second port, wherein an outer portion

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of at least one of the first end and the second end of the body exhibits a generally convex shape.

12. The flywheel assembly of claim 11, wherein the cylindrical middle portion of the body of the helically wound composite band is in contact with the inner surface of the composite flywheel rim, and wherein a portion of a convex surface of the dome connector at one of the first end and the second end of the body is spaced from the composite flywheel rim to define the opening between the inner surface of the composite flywheel rim and the portion of the convex surface of the dome connector.

13. The flywheel assembly of claim 1, wherein the opening between the inner surface of the composite flywheel rim and the outer portion of the dome connector is positioned in a location where the dome connector begins to curve away from the composite flywheel rim.

14. The flywheel assembly of claim 1, wherein the at least one connector comprises at least one of a polymer material or an adhesive.

15. A flywheel assembly comprising:

a shaft;

a composite flywheel rim;

a dome connector coupling the composite flywheel rim to the shaft, the dome connector including a helically wound composite band oriented at a helical angle that is offset from a central axis of the dome connector; and

at least one wedge-shaped connector positioned in an opening formed between an inner surface of the composite flywheel rim and an outer portion of the dome connector in a location where the dome connector begins to curve away from the composite flywheel rim, the at least one connector being relatively more flexible than the composite flywheel rim and the dome connector, the at least one connector having a first, narrow end positioned within the opening at the location where the dome connector begins to curve away from the composite flywheel rim and a second, wider end positioned in an annular space extending between the dome connector and the composite flywheel rim where the dome connector curves away from the composite flywheel rim.

16. A flywheel assembly comprising:

a shaft;

a composite flywheel rim;

a dome connector coupling the composite flywheel rim to the shaft, the dome connector including a helically wound composite band oriented at a helical angle that is offset from a central axis of the dome connector, wherein the helically wound composite band comprises a body having a first end, a second end, and a cylindrical middle portion positioned between the first end and the second end, the cylindrical middle portion of the body of the helically wound composite band being in contact with an inner surface of the composite flywheel rim, a portion of an outer surface of the dome connector at one of the first end and the second end of the body being spaced from the composite flywheel rim to define an annular opening between the inner surface of the composite flywheel rim and the portion of the outer surface of the dome connector; and

at least one connector positioned in the annular opening, the at least one connector having a first end positioned adjacent to a first location where the cylindrical middle portion of the body of the helically wound composite band is in contact with the inner surface of the composite flywheel rim and a second end positioned in a second location relatively further away from the first

location where the one of the first end and the second end of the body is spaced from the composite flywheel rim to define the annular opening, the first end of the at least one connector exhibiting a first width extending in a direction between the dome connector and the inner surface of the composite flywheel rim, the second end exhibiting a second width extending in the direction between the dome connector and the inner surface of the composite flywheel rim that is greater than the first width of the first end.

17. The flywheel assembly of claim 16, wherein another portion of the outer surface of the dome connector at the other one of the first end and the second end of the body is spaced from the composite flywheel rim to define another annular opening between the inner surface of the composite flywheel rim and the another portion of the outer surface of the dome connector, the at least one connector comprising at least another connector positioned in the another annular opening.

18. The flywheel assembly of claim 16, wherein the composite flywheel rim is formed over the dome connector and the composite flywheel rim and the dome connector are cured together to couple the dome connector to the composite flywheel rim.

19. The flywheel assembly of claim 16, wherein the annular opening between the inner surface of the composite flywheel rim and the portion of the outer surface of the dome connector is formed in a location where the dome connector begins to curve away from the composite flywheel rim.

20. The flywheel assembly of claim 16, wherein the at least one connector comprises at least one of a rubber, an elastomer, and an adhesive.

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